

The giant radio flare of Cygnus X-3 in September 2016

Trushkin S.A.,^{1,2}, Nizhelskij N.A.,¹, Tsybulev P.G.¹ and Zhekanis G.V.¹

¹*Special astrophysical Observatory RAS, Nizhnij Arkhys,
Karachaevo-Cherkassia, Russia; satr@sao.ru*

²*Kazan Federal University, Kazan, Republic of Tatarstan, Russia*

Abstract. In the long-term multi-frequency monitoring program of the microquasars with RATAN-600 we discovered the giant flare from X-ray binary Cyg X-3 on 13 September 2016. It happened after 2000 days of the 'quiescent state' of the source passed after the former giant flare (~ 18 Jy) in March 2011. We have found that during this quiet period the hard X-ray flux (Swift/BAT, 15-50 keV) and radio flux (RATAN-600, 11 GHz) have been strongly anti-correlated. Both radio flares occurred after transitions of the microquasar to a 'hypersoft' X-ray state that occurred in February 2011 and in the end of August 2016. The giant flare was predicted by us in the first ATel (Trushkin et al. (2016)). Indeed after dramatic decrease of the hard X-ray Swift 15-50 keV flux and RATAN 4-11 GHz fluxes (a 'quenched state') a small flare (0.7 Jy at 4-11 GHz) developed on MJD 57632 and then on MJD 57644.5 almost simultaneously with X-rays radio flux rose from 0.01 to 15 Jy at 4.6 GHz during few days. The rise of the flaring flux is well fitted by an exponential law that could be an initial phase of the relativistic electrons generation by internal shock waves in the jets. Initially spectra were optically thick at frequencies lower 2 GHz and optically thin at frequencies higher 8 GHz with typical spectral index about -0.5 . After maximum of the flare radio fluxes at all frequencies faded out with exponential law.

Monitoring program of microquasars with the RATAN-600 telescope

We have carried out the long-term monitoring almost daily measurements during a year GRS1915+105, SS433, Cyg X-1, Cyg X-3, LSI+61d303, LS5039 with RATAN-600 at 2.3, 4.6, 8.2, 11.2, 21.7 GHz (sometimes at 1.2 and 30 GHz) during last 6 years (or more 2000 days) (Trushkin (2000); Trushkin et al. (2012)). We have detected a lot of very bright flares (more than 1.5 Jy at 4.8 GHz) from SS433. Often, once per month we detected the bright (>100 mJy) flares from GRS1915+105. We have detected persistent but variable radio emission from Cyg X-1. Already during 36 orbital periods (26.5d) we continue to study the super-orbital modulation ($P_2 = 1666$ days) of the flaring radio emission from LSI+61d303. The mean per some orbits radio light curves depend strongly on phase P_2 . Almost 2000 days of the 'quiescent state' of the Cyg X-3 have passed after the former giant flare (~ 18 Jy) in the end of March 2011. We have detected it with RATAN-600 at 2.3-30 GHz. By the way we have found that during this quiet period the hard X-ray flux (Swift/BAT, 15-50 keV) and radio flux (RATAN-600, 11 GHz) were strongly and anti-correlated ($\rho = -0.85$) (1). The nature of this linear regression could be related with properties of the compact radio jets, forming during such 'quiescent' state and strongly depending on an accretion rate on to a black hole (or a neutron star).

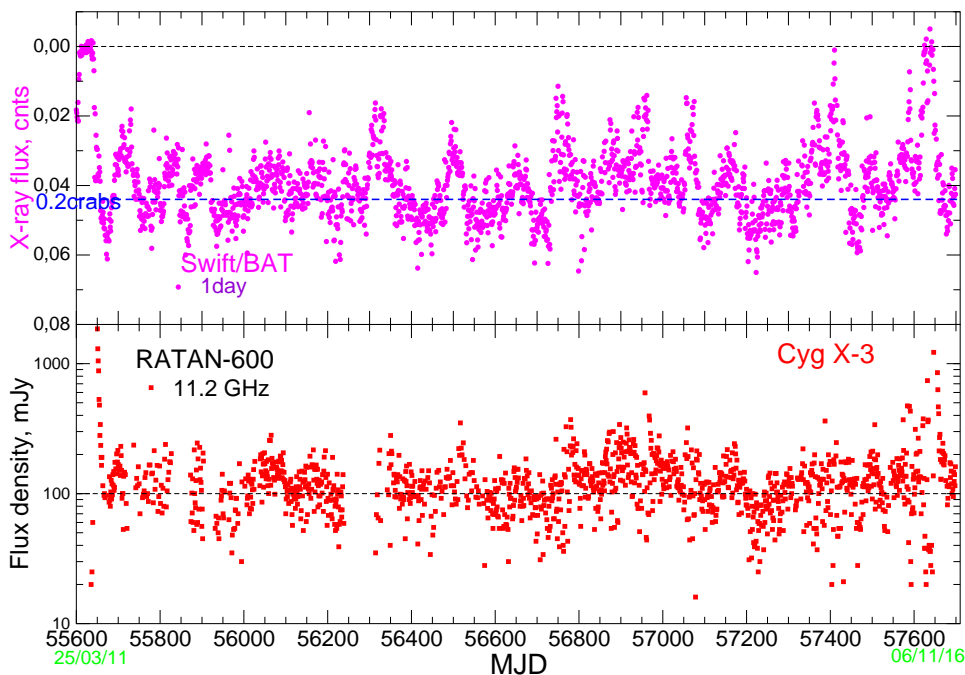


Figure 1. The light curves of Cyg X-3 at 11 GHz (RATAN-600) and at 15-50 keV (Swift/BAT) during 2011-2016. For the best comparison the axis of X-ray fluxes is directed downwards.

A new flare of Cyg X-3 in September 2016

The last two giant radio flares occurred after transitions of the microquasar to 'hyper-soft' X-ray state that occurred in February 2011 and in the end of August 2016. The flux of the recent flare on MJD 57643.8 rose from 0.01 to 15 Jy at 4.6 GHz during five days. The giant flare was predicted by us (Trushkin et al. (2016)). Indeed after a dramatic decrease of the hard X-ray 15-50 keV flux (Swift/BAT) lower the detection level radio fluxes decreased also to 10-30 mJy (a 'quenched state'). But then the both band fluxes increased in a small flare, about 0.7 Jy at 4-11 GHz, then fade to a quenched state again, and then at last increased almost simultaneously with increase of the hard X-ray flux. The rising of the flaring flux is well fitted by a exponential law $\propto \exp[(t - t_0)/0.54\text{day}]$ at 11 GHz, where $t_0 = 57644.5$ is a probable start MJD-date of the flare. After maximum of the flare the all radio fluxes at all frequencies faded out with exponential law $\propto \exp[-(t - t_m)/2\text{day}]$ where $t_m = 57650.7$ is the date of the maximal fluxes and Cyg X-3 came back to 'quiescent state' on 18 October 2016. After three-five days the flaring spectra became optically thin at 11-22 GHz with same spectral index 3. Its value equal to -0.5 ($S_\nu \propto \nu^\alpha$ is direct evidence of the first-order Fermi acceleration, although the evolved internal shock is probably relativistic).

Discussion

The giant flares have been often detected in the GBI two-frequency monitoring program and Waltman et al. (1994) have detected that flares occur after 'quenched state', when radio fluxes decreased to 10-30 mJy at 2-8 GHz. McCollough et al. (1999) analyzed

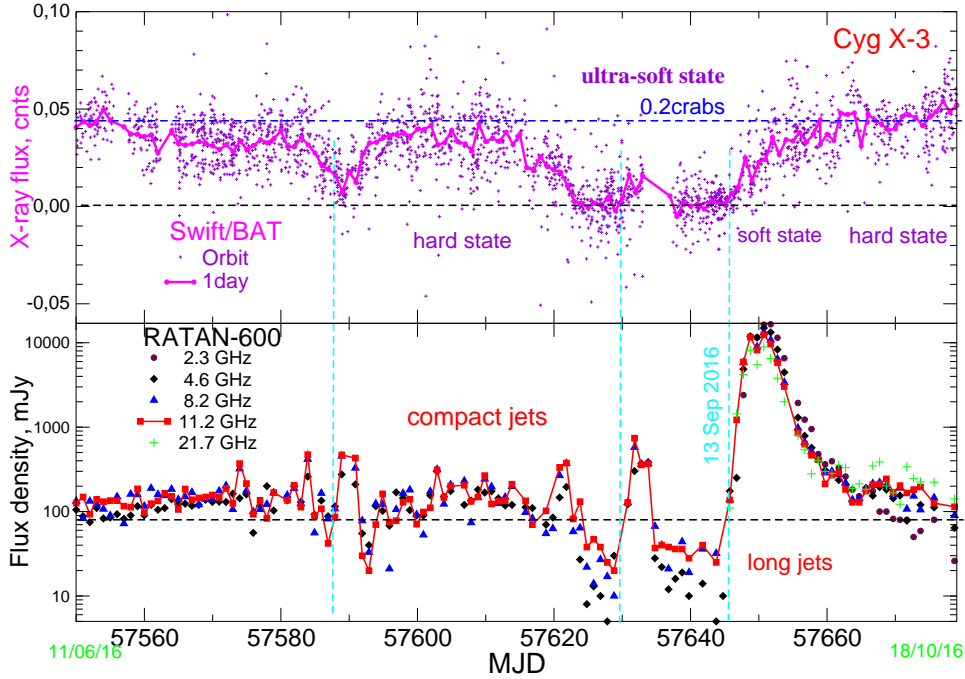


Figure 2. Light curves before or during the flare at X-ray 15-50 KeV (top) and the multi-frequency data of the RATAN measurements (below). Characteristic X-ray states of the binary are marked.

the giant flare of 1999 and found that the radio fluxes have anti-correlated with the hard (BATSE) X-ray fluxes and correlated during the flare. The active period of the Cyg X-3 in 2006-2009 showed similar dependencies between soft (RXTE ASM), hard (Swift/BAT) X-rays and radio emission (Williams et al. (2011); Corbel et al. (2012); Trushkin et al. (2006) or even with gamma-ray emission Tavani et al. (2009); Piano et al. (2012,?). The accretion disk-jet coupling in X-ray binaries has been discussed during last 10-15 years especially in the frame of the hardness-intensity diagram (HID) studies (Fender et al. (2004)). Based on the first-time developed HID of the microquasar Cyg X-3 Koljonen et al. (2010) have detected the 'jet-line' of the powerful ejections only after so-called a 'hyper-soft' state, when hard X-ray fluxes fallen down to detection level, meanwhile soft X-ray emission stays on high level. Trushkin et al. (2006) have successfully applied computer routine to model radio flaring activity (in July 2006) of Cyg X-3, based on the model created by Marti et al. (1992) and found main parameters: magnetic field (~ 0.05 Gs), thermal electron densities ($3 \times 10^5 \text{ cm}^{-3}$) and the bulk speed of jets ($\sim 0.5c$). The spectral evolution of the giant flare is described by a single (during 3-4 days) ejection of the relativistic electrons, that moved with high velocity ($\sim 0.5c$) away from the binary and expanded as a conical structure. During first days of the ejection jets is probably optically thick due to synchrotron self-absorption or by thermal electrons mixed with relativistic ones. It is interesting that just in the beginning of the new flare in September 2016 the MAXI sort X-ray (2-20 keV) fluxes decreased from 0.35 crabs to 0.1 crabs thus Cyg X-3 returned in hard state.

A lot of collected measurements of the flare with different telescopes will be presented in the preparing paper.

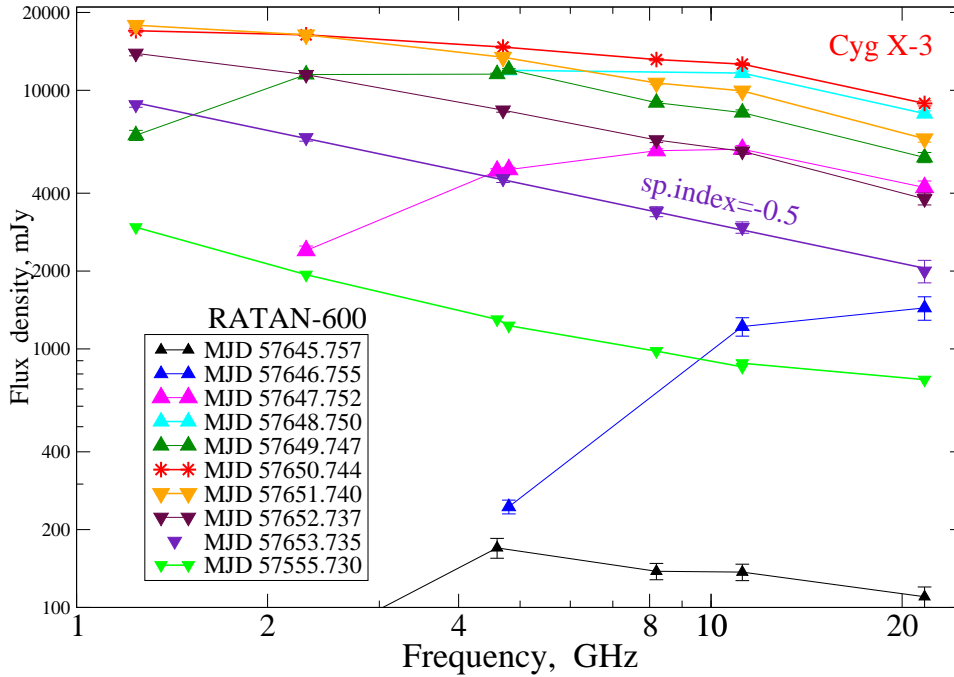


Figure 3. The radio spectra during first ten days of flare. There is clear transition from the optically thick mode to the optically thin one after MJD 57650.

Acknowledgments. S.A.T. acknowledges support through the Russian Government Program of Competitive Growth of Kazan Federal University.

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